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DOWEL BAR RETROFIT

STH 13 CONSTRUCTION
&
ONE-YEAR PERFORMANCE REPORT

NOVEMBER 2002

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16. Abstract

From May to July, 2001, WisDOT rehabilitated STH 13 in Wood County using retrofitted dowel bars. The objective of the dowel bar retrofit was to provide load transfer in the jointed plain concrete pavement and to prevent further faulting from occurring. Fifteen test sections and three control sections were established in this study to examine the performance of six different patch materials, the performance of two different dowel bar materials, and the effects of sealed and unsealed joints on dowel bar retrofit.

The potential benefits of this project include improving the ride quality, reducing future maintenance needs, and extending the pavement service life.

Patch material performance was assessed by test results including compressive strength at 7 and 28 days, air void content, permeability, and freeze/thaw durability. A one-year field review evaluating the in situ performance of the different patch materials was also conducted. While the Tamms Speed Crete 2028 performed the best in laboratory testing, the field review showed debonding and microcracks of both the Tamms Speed Crete 2028 and the Mn/DOT Specification 3U18 patch materials. To date, the other patch materials are performing well and show no distresses after one year in service. The long-term performance of the patch materials has not yet been determined.

The test sections will continue to be monitored and inspected for deterioration, spalling, or scaling of the patch material, deterioration of the pavement around the dowel bar slots, faulting of the slabs, corrosion of the dowel bars, and overall pavement performance. Performance and test results may result in modifications to WisDOT's material and construction specifications for DBR.

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WisDOT Highway Research Study # WI-98-05

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INTRODUCTION

Currently, all new Wisconsin roadways constructed of jointed concrete pavement contain dowel bars across the joints as a means to transfer load from one slab to the next. During most of the 1940's, and also during a brief period from the mid '70s to the mid to late '80s, the importance and cost-effectiveness of dowel bars for load transfer were not fully understood and dowel bars were not installed in new concrete pavements. As a result, these older roadways have little or no effective means of transferring load from one slab to the next. The inability to transfer load results in faulting of slabs, which is a difference in slab elevations across a joint or crack. This faulting creates a very rough and bumpy ride.

Dowel bar retrofit (DBR) is a technique used to rehabilitate jointed concrete pavements where faulting is a problem, but are otherwise in good condition. Slots are cut into the roadway over the joints and existing transverse cracks. Dowel bars are set in the slots at mid-pavement depth and then the slots are backfilled with a patch material. Later, the pavement is diamond ground so the tops of the slabs are flush with each other. The objective of DBR, besides restoring a smooth ride, is to extend the service life of an older pavement 10-15 years by providing it with the ability to effectively transfer load.

Over a two-year period of 1999 and 2000, portions of I-39 throughout Marquette, Waushara, and Portage Counties of Wisconsin were rehabilitated using the DBR technique as part of a WisDOT research study (WisDOT Research Study # WI-98-05). In February of 2001, I-39 was inspected and it was found that the patch material used to backfill the slots around the dowel bars was deteriorating at the joints in many areas of the project. Although the severity of the deterioration varied throughout the project, it was observed in many of the locations that were inspected (see WisDOT Report #RED-05-01, Report on Early Distress (RED) Retrofit Dowel Bars on I-39). As a result of this and other problems that have arisen from previous DBR projects, in the spring of 2001, WisDOT issued a moratorium on all DBR projects until more knowledge is gained on the long-term viability of DBR in Wisconsin.

The DBR project on State Trunk Highway (STH) 13, let prior to the moratorium, was designed to take into account knowledge gained during the course of the RED investigation. It was dovetailed into the ongoing I-39 DBR research study for two main purposes: (1) to determine if DBR is a suitable and cost effective restoration and/or preservation technique for jointed reinforced or jointed plain concrete pavements and (2) to evaluate the performance of different patch and dowel bar materials as well as different joint treatments in a dowel bar retrofit project. Patch material performance will be assessed by evaluating the laboratory test results (compressive strength at 7 and 28 days, air void content, permeability, and freeze/thaw durability) and the in situ performance of the different mixes. The amount of corrosion developing over time and its effect on pavement performance and service life will be examined to evaluate the different dowel bar materials. The effect of the joint treatment (sealed vs. unsealed) on the retrofit will be determined by inspecting the condition of the joint, including the condition of the patch material at the joint.

Based on the performance of the test sections, this study will help establish if dowel bar retrofit is a viable and cost effective concrete rehabilitation technique for faulted non-doweled, jointed plain or jointed reinforced concrete pavements in Wisconsin. Performance and test results will aid in refining the material and construction specifications and also in determining if the current moratorium on DBR projects in Wisconsin should be lifted.

PROJECT OVERVIEW

Dowel bar retrofit work began in May 2001 and was completed in July 2001, under project ID 1620-00-60. The test sections are located on STH 13, a four-lane highway just south of the city of Marshfield, in Wood County, Wisconsin. The total length of the project is approximately 1.7 miles long, with about 5.3 lane-miles of DBR. The southern limit of the test sections is approximately 1125 feet (0.2 miles) south of the STH 13 E/ United States Highway (USH) 10 intersection; and, the northern limit is approximately 1643 feet (0.3 miles) north of the STH 13 E / 26th St. intersection (Figure 1, page 40).

The project is located within an urban setting with a maximum posted speed limit of 45 m.p.h. on the south end of the project and 35 m.p.h. on the north end of the project. In 1999, the average daily traffic on that segment of road was 9300, 7%-10% of which was truck traffic.

The existing pavement was originally a 2-lane highway that was constructed in 1949 as a 9-inch thick jointed plain concrete pavement with random spaced (13 ft, 19 ft, 18 ft, and 12 ft) joints, $^{3}/_{8}$-inch wide, and perpendicular to the centerline. In 1986, this pavement was expanded into a 4-lane highway. The inner two lanes of the original pavement, from Station 210+66 to 248+54 (3,788 feet), remained in place and received a $2^{3}/_{4}$ to $3^{7}/_{8}$ in. bonded concrete overlay. The inner two lanes with the bonded concrete overlay was not retrofit with dowels in 2001, and was diamond ground only, comprising two of the control sections. The joints in the bonded concrete overlay and the adjacent outer lanes were the same as the existing underlying pavement (random spaced, $^{3}/_{8}$-inch wide, and perpendicular to the centerline). The pavement south of Station 210+66 and north of Station 248+54 was removed and replaced with new concrete. The new pavement, including the two new lanes, was an 8-inch jointed plain concrete pavement over a 6-inch crushed aggregate base course, with an 18-inch granular subbase. The joints in these sections were also random spaced and $^{3}/_{8}$-inch wide, but were skewed 6:1, right hand forward, rather than perpendicular. All lanes were tied together with #4 (½-inch diameter) rebar.

The pavement was in relatively good condition, with slight faulting (up to ¼-inch) of the non-doweled joints. The International Roughness Index (IRI) is a ride quality measurement based on pavement roughness. In 2000, the average IRI value over the project length was 2.1 mm/m. This value is a reflection of the faulting present in the non-doweled pavement. The Pavement Distress Index (PDI) is an index that reflects the condition of the pavement based on the distresses (extent and severity) present. The PDI scale ranges from 0 to 100, with 0 reflecting a new pavement with no distresses. In 2000, the average pavement distress index over the project length was 9, which indicates a pavement with little distress. This pavement was a good candidate for dowel bar retrofit, because it was in good condition with the exception of faulting at the joints. Thus, this pavement was selected to receive DBR to restore the load transfer at the joints and extend the service life of the pavement. The pavement would also be diamond ground to reestablish a smooth ride.

As Figure 2 on page 41 illustrates, this research study is composed of 15 test sections and three control sections. These test sections will test the performance of four different patch materials (two of them at different extension ratios), the effects of sealed and unsealed joints on a dowel bar retrofit project, and the performance of two different dowel bar materials. The extension ratios were selected based on previous WisDOT field experience and the manufacturers' recommendations.

The extension ratio is the ratio of the weight of coarse aggregate to the weight of mortar mix (see Equation 1 below). For "single component" mortar mixes in which the cement is pre-mixed with the sand by the manufacturer, extension calculations are straightforward. A 100% extension ratio of coarse aggregate to mortar mix is 1:1, an 80% extension ratio is 0.8:1, and a 60% extension ratio is 0.6:1. For concrete or grout patch material mixes that require the cement, sand, and coarse aggregate to be added separately (two-part mortar mixes), the proportion of mortar mix required is the sum of the proportions of the sand and cement. A 100% extension ratio of cement to sand to coarse aggregate is 1:1.5:2.5 and a 60% extension ratio is 1:1.5:1.5.

<u>Equation 1.</u>

$$\text{Extension} = \underbrace{\frac{\text{Weight of Coarse Aggregate}}{\text{Weight of Mortar Mix}}}_{\text{“single component” mortar mix}} = \underbrace{\frac{\text{Weight of Coarse Aggregate}}{(\text{Weight of Cement} + \text{Weight of Sand})}}_{\text{Two-part mortar mix}}$$

The patch materials being tested include:

- American Highway Technology Highway DB Retrofit Grout at 60% extension
- American Highway Technology Highway DB Retrofit Grout at 100% extension
- Tamms Speed Crete 2028 Rapid Setting Mortar at 80% extension
- Tamms Speed Crete 2028 Rapid Setting Mortar at 100% extension
- ThoRoc 10-60 Rapid Mortar (and 10-60C Rapid Cement concentrate) at 60% extension
- Minnesota DOT (Mn/DOT) Specification 3U18 Concrete Mix (includes air entrainer)

The dowel bar materials being tested are:

- 15 in. long, 1 ¼ in. diameter Nuovinox stainless steel clad dowel bars
- 18 in. long, 1 ¼ in. diameter epoxy coated steel dowel bars

TEST SECTIONS

Test Section A STA 191+45 TO STA 214+09

- Mn/DOT Specification 3U18 Concrete Mix (includes air entrainer)
- 2264 ft. long, located in the northbound driving lane
- The joints in this section were sealed with Sealtight® 3405.

Test Section B STA 214+09 TO STA 236+81

- Mn/DOT Specification 3U18 Concrete Mix (includes air entrainer)
- 2272 ft. long, located in the northbound driving lane
- The existing sealant was removed from the joints in this section and the joints were left unsealed.

Test Section C STA 236+81 TO STA 259+37

- American Highway Technology, Highway DB Retrofit Grout at 60% extension
- 2256 ft. long, located in the northbound driving lane
- The existing sealant was removed from the joints in this section and the joints were left unsealed.

Test Section D STA 259+37 TO STA 282+00

- American Highway Technology, Highway DB Retrofit Grout at 60% extension
- 2263 ft. long, located in the northbound driving lane
- The joints in this section were sealed with Sealtight® 3405.

Test Section E STA 191+45 TO STA 210+66

- American Highway Technology, Highway DB Retrofit Grout at 100% extension
- 1921 ft. long, located in the northbound passing lane
- The joints in this section were sealed with Sealtight® 3405.

Test Section F STA 248+63 TO STA 256+32

- American Highway Technology, Highway DB Retrofit Mortar at 100% extension
- 769 ft. long, located in the northbound passing lane
- The existing sealant was removed from the joints in this section and the joints were left unsealed.

Test Section G STA 256+32 TO STA 259+37

- ThoRoc 10-60C Rapid Cement (concentrated mix) at 60% extension
- 305 ft. long, located in the northbound passing lane
- The existing sealant was removed from the joints in this test section and the joints were left unsealed.

Test Section H STA 259+37 TO STA 282+00

- ThoRoc 10-60C Rapid Cement (concentrated mix) at 60% extension
- 2263 ft. long, located in the northbound passing lane
- The joints in this section were sealed with Sealtight® 3405.

Test Section I STA 282+00 TO STA 276+50

- Tamms Speed Crete 2028 Rapid Setting Mortar at 100% extension
- 550 ft. long, located in the southbound driving lane
- The joints in this section were sealed with Sealtight® 3405.

Test Section J STA 276+50 TO STA 248+63

- Tamms Speed Crete 2028 Rapid Setting Mortar at 80% extension
  * The mortar for the southern portion of this section was mixed in a paddle mixer.
- 2787 ft. long, located in the southbound driving lane
- The joints in this section were sealed with Sealtight® 3405.

Test Section K STA 248+63 TO STA 236+73

- ThoRoc 10-60C Rapid Cement (concentrated mix) at 60% extension
- 1190 ft. long, located in the southbound driving lane
- The existing sealant was removed from the joints in this section and the joints were left unsealed.

Test Section L STA 236+73 TO STA 202+81

- Tamms Speed Crete 2028 Rapid Setting Mortar at 80% extension
  (mixed by paddle mixer)
- 3392 ft. long, located in the southbound driving lane
- The existing sealant was removed from the joints in this section and the joints were left unsealed.

Test Section M STA 202+81 TO STA 191+45

- Tamms Speed Crete 2028 Rapid Setting Mortar at 80% extension
  (mixed by paddle mixer)
- 1136 ft. long, located in the southbound driving lane
- This section contains Nuovinox stainless steel clad dowel bars in place of the epoxy coated steel dowel bars.
- The existing sealant was removed from the joints in this test section and the joints were left unsealed.

Test Section N STA 282+00 TO STA 248+63

- American Highway Technology, Highway DB Retrofit Grout at 100% extension
- Approximately 3337 ft. long, located in the southbound passing lane
- The joints in this section were sealed with Sealtight® 3405.

Test Section O STA 210+66 TO STA 196+70

- ThoRoc 10-60 Rapid Mortar at 60% extension
- 1396 ft. long, located in the southbound passing lane
- The existing sealant was removed from the joints in this section and the joints were left unsealed.

Control Section 1 STA 210+66 TO STA 248+63

- This section received diamond grinding only (no dowel bar retrofit).
- 3797 ft. long, located in the northbound passing lane
- The existing sealant was removed from the joints in this section and the joints were left unsealed.

Control Section 2 STA 248+63 TO STA 210+66

- This section received diamond grinding only (no dowel bar retrofit).
- 3797 ft. long, located in the southbound passing lane
- The existing sealant was removed from the joints in this section and the joints were left unsealed.

Control Section 3 STA 196+70 TO STA 191+45

- This section received diamond grinding only (no dowel bar retrofit).
- 525 ft. long, located in the southbound passing lane
- The existing sealant was removed from the joints in this section and the joints were left unsealed.

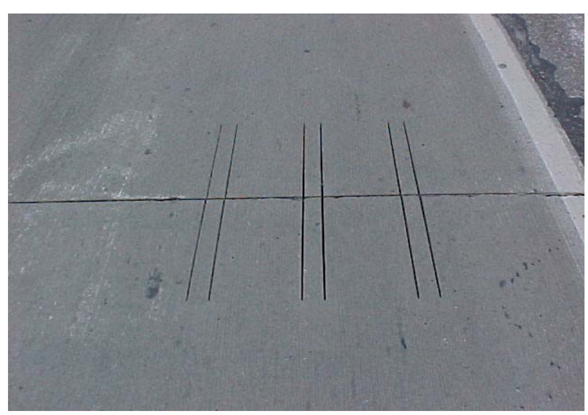
Note: Control Section 1 and Control Section 2 are the bonded concrete overlay segments as described on page 3.

CONSTRUCTION PROCESS

Preparing the Slots

To begin the dowel bar retrofit process, a gang saw with 21-inch diameter diamond tipped blades was used to make 12 saw cuts across the joint or transverse crack, parallel to the centerline (Photographs 1 and 2). The saw cuts were approximately 5½ inches deep, allowing enough room for the chairs to hold the dowel bars at mid-pavement depth, and approximately 37 inches long.

Photograph 1. Diamond tipped saw blade attachments are used to cut into the pavement.



Photograph 2. Six saw cuts are made over the joint in each wheel path to provide three dowel bar slots.

Thirty-pound jackhammers were used to clear the concrete pavement between the saw cuts, thus providing three slots in each wheel path (Photograph 3). The slots were 2½ inches wide and were spaced 12 inches apart on center. After jackhammering, workers scraped the concrete debris from the slots with pickaxes. The cleared slots were inspected to make sure the jackhammering created a level surface at the bottom of the slot so the chairs would hold the dowel bar in the correct position (level and parallel to the pavement surface). It was found that some slots did not have level bases due either to deteriorated pavement or poor jackhammering. When the dowel bars were placed later in the process, it was found that a few of the dowel bars placed in these slots tended to be slightly off center on the joint and slightly tilted so that they were not level with the top surface of the pavement. These dowel bars were adjusted to achieve the best possible position before proceeding.

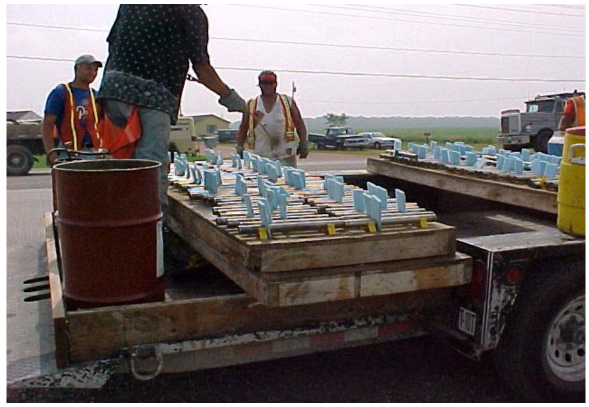
Photograph 3. A jackhammer is used to clear the slots.

Next, the slots were sandblasted with abrasive sand. After sandblasting, the sand and other debris were blown out of the slots with a compressed air blower (Photograph 4,). In order to inspect the slots for satisfactory cleaning, the sides of the slots were checked by hand to ensure all remaining dust from the sawing process had been removed.

Photograph 4. Compressed air is used to blow any debris out of the slots.

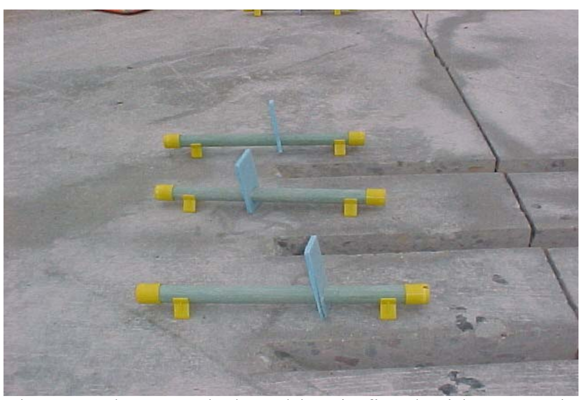
Preparing the Dowel Bars

Two types of dowel bars were used in this project: standard epoxy coated steel dowel bars and Nuovinox stainless steel clad dowel bars. The standard epoxy coated steel dowel bars were 18 inches long and 1¼-inch diameter. These bars have a manufacturer-applied bond breaker. The Nuovinox dowel bars, manufactured by Stelax Industries, Ltd., were 15 inches long with a 1¼-inch diameter. Nuovinox dowel bars contain carbon steel cores and are clad with type 316L stainless steel alloy. Literature indicates that these dowel bars have a high level of corrosion resistance and are similar in properties to solid stainless steel. These bars were coated with oil, which acts as a bond breaker, before they were placed (Photograph 5).



Photograph 5. Oil is sprayed onto the stainless steel clad dowel bars before they are fitted with end caps, to act as a bond breaker.

Each dowel bar was fitted with a foam board, two plastic chairs, and two plastic end caps (Photograph 6). The piece of foam board was slipped onto the dowel bar and centered to provide a tight seal at the joint or crack. This seal prevents any patch material from flowing into the joint or crack and maintains its continuity. The chairs were placed on each end of the dowel bar in order to keep it centered between the sides of the slot and to elevate it from the bottom of the slot, thus enabling the patch material to fully encase the bar when it was poured. The dowel bar end caps have a slight ledge around the interior circumference to keep ¼-inch of space between the end of the dowel bar and the end of the cap. This extra space prevents any strain between the dowel bar and the patch material from occurring as the concrete expands and contracts during temperature changes.



Photograph 6. Each dowel bar is fitted with two end caps, two chairs, and a foam board.

Placing the Dowel Bars

Once the slots had been cleaned, workers began caulking the slots. A bead of siliconized acrylic sealant was applied across the bottom of the slot in line with the joint or crack. Then, the dowel bar was set into place (Figure 3, page 42). The placement was checked to make sure the foam board lined up with the joint or crack and that the bottom of the foam board was resting in the bead of caulk. This is especially important when working with skewed joints, as the workers had the tendency to line the foam board up perpendicular to the slot instead of angling it to line up with the skewed joint as required.

With the foam board secured in the correct position, the dowel bar was adjusted within the foam by sliding it back and forth in attempt to obtain an equal length of dowel bar on each side of the joint. The dowel bars were also checked to make sure that the chairs were resting on a level surface and that they were keeping the bar centered between the sides of the slot. Once the inspector approved the dowel bar placement, another bead of caulk was applied to each side of the foam where the side of the foam board meets the side of the slot. This work was done using an elbow attachment on a caulk gun (Photograph 7). The caulking was checked to make sure that it secured the position of the foam and sealed up any locations where patch material might seep into the joint or crack.

Photograph 7. The crew applies sealant to the sides of the foam board using elbow attachments on their caulk guns

Calibrating the Mobile Mixer

James Cape and Sons Co., the contractor on this project, used a mobile mixer to mix the patch material mix with the coarse aggregate (stone) and sand for the majority of the patch materials. A mobile mixer is a truck-mounted unit that measures and mixes materials volumetrically. It has separate compartments for coarse aggregate, sand, cement, and water. The volume of dry material discharged is regulated as it is dropped onto a conveyor belt and delivered to the mixing screw auger. The dry materials are then mixed with water in the mixing screw auger and discharged from the chute.

The mobile mixer was calibrated for cement, sand, and coarse aggregate before every pour. To calibrate the mobile mixer for cement, the cement was first loaded into the cement hopper of the mixer. The cement was then agitated in the hopper and dispensed by a metering auger. The mixer was run for a short period of time to push any debris out of the chute so only a constant volume of cement was dispensed. Then, the mixer was turned on for ten seconds, timed by a stopwatch. The cement was dispensed out of the chute into a plastic bucket by the mixing auger (Photograph 8). This bucket was then weighed on a digital scale, accurate to ½-pound (Photograph 9). Ten trials were documented and the average weight of cement the mixer dispensed in ten seconds was used to calculate how much sand and coarse aggregate were needed based on the extension ratios of the different patch materials. For "single component" mortar patch material mixes in which the cement is pre-mixed with the sand by the manufacturer, the average weight of the mortar (sand/cement combination) dispensed is used to calculate the amount of coarse aggregate needed. The mortar is loaded in the sand hopper of the mobile mixer instead of the cement hopper.

Photograph 8. During calibration of the mobile mixer, the mixer runs cement out of the chute for a ten-second interval.

Photograph 9. During calibration, the cement dispensed in a ten-second interval is weighed.

Once the cement calibration was complete, the sand (for two-part mortar mixes) was loaded into the sand hopper of the mixer. The mixer was run until any remaining cement had been pushed out of the chute. Then, the calibration trials of the sand began, each lasting for approximately ten seconds. The flow control gate to the hopper was adjusted after each set of trials until the mixer consistently dispensed the required amount of sand. The inspector made sure that each time the gate to the hopper was adjusted, the mixer ran the sand out of the chute as waste until a constant volume was achieved.

The mixer was calibrated for the coarse aggregate the same way it was calibrated for the sand. Once the coarse aggregate calibration was complete, the gates were no longer allowed to be adjusted and the mixer was ready to pour.

<u>Pouring the Patch Material</u>

Before the pour began, the slots were blown clean one last time with a leaf blower and then wet down with water using a manual pressure sprayer (Photographs 10 and 11).

Photograph 10. A leaf blower is used to clean the slots one last time before the patch material is poured.

Photograph 11. The slots are wet down with water before the patch material is poured.

Next, the mobile mixer ran the patch material into the bucket of a wheel loader until it reached the proper consistency (Photograph 12). The material in the bucket of the loader was considered waste and discarded. The workers began the pour by backfilling the patch material into the slots with shovels making sure not to damage the foam board in the process (Photographs 13 and 14).

Photograph 12. The mixer runs the patch material off into the bucket of a loader as waste until the patch material reaches the desired consistency.

Photograph 13. The patch material is backfilled into the slots.

Photograph 14. Care is taken not to damage the foam board during backfilling.

Next, a spud vibrator with a 1¼-inch diameter head was inserted into the patch material on each side of the foam board to consolidate the patch material around the dowel bar (Photograph 15). The filled slots were then leveled off with shovels, flush with the adjacent concrete pavement (Photograph 16).

Photograph 15. A spud vibrator is inserted in the slot on each side of the foam board to consolidate the patch material around the dowel bar.

Photograph 16. Shovels are used to level the slots so that the surface of the fresh patch material is flush with the adjacent concrete pavement.

The finishers smoothed the surface of the filled slots with a trowel and made sure the foam board was still aligned with the joint or crack (Photograph 17). Care was taken to make sure the backfilling did not get too far ahead of the finishers or else the patch material would have hardened in the slots by the time the finishers reached it. The clean up crew followed the finishers to scrape any extra patch material off the pavement before it dried (Photograph 18). Lastly, a white-pigmented, wax type, water-based concrete curing compound (Sealtight 1600-White) was sprayed over the filled slots, with a gas powered pressurized sprayer (Photograph 19).

Photograph 17. The finishers make sure the foam board is still aligned with the joint as they trowel the surface smooth.

Photograph 18. The extra patch material is scraped off the pavement before it hardens.

Photograph 19. Curing compound is sprayed onto the pavement soon after the slots are finished.

Finishing the Joint

Within 24 hours of the pour, saw cuts were made to restore the transverse joints or cracks. The saw cuts were made deep enough and wide enough across the lane to remove all of the patch material from the joint. At that time, any old remaining sealant was removed from the joint. After the patch material had fully cured, the entire concrete roadway was diamond ground to remove the existing faulting at the joints and to provide a smoother ride (Photographs 20, 21, and 22). The joints in the designated test sections were then sealed with Sealtight® 3405 (ASTM D-3405). Sealtight® 3405 polymeric compound is a hot applied, single component, asphalt joint sealant.

Photograph 20. A diamond grinder grinds down the entire lane.

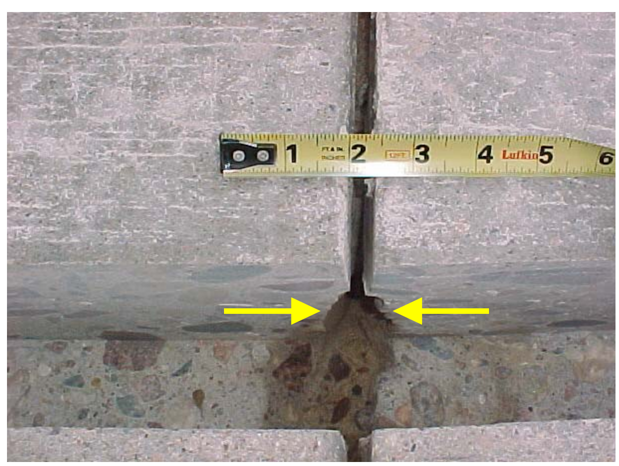
Photograph 21. Diamond grinding removes any previously existing faulting.

Photograph 22. This view is a close-up of a joint and one DBR slot after diamond grinding.

COMPLICATIONS

<u>Pavement Issues</u>

As standard practice, when STH 13 was initially constructed the transverse joints were only cut a few inches deep. The remaining concrete beneath the saw cut was left to crack on its own. The cracking of the cement paste around individual stones within the concrete creates a jagged break at the joint. At the time, it was believed that the jagged joint created from this cracking process would provide enough aggregate interlock to effectively transfer load. This assumption proved to be incorrect. Over time, the jagged edges of the slabs beneath the joint cuts wore away at each other and no longer provided enough aggregate interlock to transfer the loads effectively. The gaps between the slabs, where the aggregate and concrete have worn away, created some difficulties with dowel bar placement since it is not possible to line up a straight piece of foam board with a jagged joint (Photograph 23). This problem was evident in each test section. Caulk was used to seal these joint gaps, found at the bottom of the slot sidewalls, to prevent the mortar from entering.



Photograph 23. The concrete slabs have worn each other away beneath the joint saw cut.

Severe deterioration of the concrete pavement at the base of the slots was also noticed in some of the slots (Photograph 24). The deterioration appeared to have occurred from the bottom up, creating big voids in the bottom of the pavement. This problem was most prevalent in areas of lower elevation, especially in the slots near the outside edge of the roadway. Initially the voids were filled with caulk but it was determined that this was not a cost-effective solution for the remaining work. Filling these voids with concrete patch material, during the fill of the slots, was not considered since that could create further problems due to point loadings during warm temperatures when the adjacent concrete slabs expand. Using a longer piece of foam board was discussed as a possible solution, but it was not tried due to a lack of extra foam board material on site. It was decided that flint silica sand be used to fill in these voids for the remaining work. Sand however, was not a very effective solution to this problem because it was easily blown out of the slot when the leaf blower was used to clean the slot directly before pouring.

Photograph 24. Bottom up deterioration of pavement is prevalent in areas of low elevation.

In the southbound passing lane at the intersection of STH 13 and 26th St., the cleared slots revealed the subgrade (Photograph 25). The pavement in the intersection area was found to be much thinner than the adjacent pavement, at only about 6 inches thick. For this small number of joints, the dowel bars were positioned so that the foam board held them up off of the

Photograph 25. An area of thin pavement was unexpectedly revealed when subgrade was exposed after jackhammering.

subgrade. It was determined that in the future, areas where thin pavement is suspected or likely should be carefully inspected using ground penetrating radar, cores, or other suitable methods prior to the project letting.

Patch Material Issues

It was extremely difficult to calibrate the mobile mixer for “single component” mortar patch material mixes in which the sand is pre-mixed with the cement by the manufacturer. Specifically for this project, the mixer could not be calibrated for the Tamms Speed Crete 2028 Rapid Setting Mortar or the ThoRoc 10-60 Rapid Mortar. One remedy that was tried to help the calibration was to place the mortar mix in the cement hopper of the mobile mixer instead of the sand hopper but this adjustment made little difference as the calibration continued to be inconsistent. The different shades of color of the mix in the hopper made it apparent that segregation of the sand and cement was occurring. The calibration weights for these mixes were extremely inconsistent with some buckets very light in weight and others very heavy.

One theory is that when the sand/cement mixture reaches the mixing auger during calibration, the sand settles around the sides of the chute and only the smaller sized cement is discharged by the auger. Eventually, enough sand builds up in the chute that the mix pushed out by the auger contains a very high proportion of sand. This theory led to a second remedy to aid in calibration, which was to replace the auger flights on the mixer. The existing flights had up to a 2-inch gap between the tip of the flight and the side of the chute (Photograph 26). Upon comparing the new flights to the existing flights, it was found that there was little noticeable difference in the size. It was concluded that the condition of the auger flights was not the cause of the problem and the new flights were not installed.

Photograph 26. Some auger flights had gaps as wide as two inches between the tip of the flight and the side of the chute.

The final solution to resolve the inconsistencies with the ThoRoc 10-60 Rapid Mortar calibrations was to order a cement concentrate (ThoRoc 10-60C Rapid Cement) from the manufacturer. Except for the test section in the southbound passing lane (labeled as Test Section O in Figure 2, page 41), the ThoRoc 10-60C Rapid Cement was used to complete the remaining ThoRoc test sections. Once the concentrate was used, no further problems, during calibration or pouring, were encountered.

It was not possible to obtain a cement concentrate from the Tamms manufacturer so the final solution for the Tamms Speed Crete 2028 Rapid Setting Mortar problems was to require the use of a paddle mixer for mixing the patch material. The Tamms Speed Crete 2028 Rapid Setting Mortar mixing instructions state, "the material is stiff initially but relaxes after 4-5 minutes of mixing[1]." The instructions go on to assert that no additional water should be added to loosen up the mix. The design of the mobile mixer makes it nearly impossible to comply with these mixing instructions since the materials are not in the chute long enough. Aside from the test sections in the northern portion of the southbound driving lane (labeled Test Sections I and J in Figure 2, page 41), James Cape and Sons Co. completed the remaining Tamms Speed Crete 2028 test sections using a paddle mixer in place of their mobile mixer. The productivity rate with the paddle mixer was about half that of the mobile mixer due to its smaller batch size. However, pouring the patch material with the paddle mixer ran without complications, as this mixer allowed for a longer mixing time (Photographs 27, 28, and 29).

Photograph 27. A paddle mixer was used to pour the majority of the Tamms Speed Crete 2028 patch material.

[1] Tamms Industries. "Technical Data Sheet, Speed Crete 2028 Rapid Setting Mortar." <http://www.tamms.com>. 2000.

Photograph 28. The Tamms patch material is poured into the bucket of a skid steer for backfilling.

Photograph 29. The paddle mixed Tamms Speed Crete 2028 is backfilled into the slots.

A separate patch material issue affecting the Mn/DOT Specification 3U18 Concrete Mix was discovered upon coring. Of the four cores taken of the Mn/DOT Specification 3U18 patch material, two of the cores revealed extremely poor consolidation of the patch material around the dowel bar chairs as well as poor bonding to the sidewalls of the slots (Photographs 30 and 31). The poor consolidation of the patch material is most likely due to the mix's low slump requirements. With a maximum slump allowance of only one inch, the patch material is very stiff, making it difficult to vibrate into place.

Photographs 30 and 31. The front and back sides of a Mn/DOT Specification 3U18 core show poor consolidation of the patch material as well as poor bonding to the sidewalls.

The debonding that has occurred in some of the slots in Wisconsin has also been observed in test sections in Minnesota, constructed with Mn/DOT Specification 3U18 mix with Type I Portland cement. At the time, it was believed that the debonding experienced by Mn/DOT was caused by slab curl cycles over a slow set period, induced by the Type I Portland cement. Prior to the DBR construction on STH 13 in Wisconsin, Mn/DOT reported that the slots that were showing debonding were still providing good load transfer, as proven by Falling Weight Deflectometer (FWD) test results, and had shown no resultant problems due to the debonding. Nevertheless, WisDOT substituted Type III Portland cement, which has a quicker set time, for the Type I in the Mn/DOT Specification 3U18 mix in hopes of alleviating the debonding. As previously mentioned, debonding still occurred in some of the slots and the slab curl cycles over a slow set period proved not to be the problem.

It is now believed that the main causes of the debonding that the Mn/DOT Specification 3U18 patch material is experiencing at the sidewalls are drying, plastic, and chemical shrinkage. Although it can be influenced by many factors, it is believed that the shrinkage occurring with the Mn/DOT Specification 3U18 patch material is a result of the type of cement used in the mix design. While the other mixes used in this study contain high alumina cements, the Mn/DOT Specification 3U18 mix consisted of ordinary Portland cement. As the mix undergoes shrinkage, the volume of the cementitious paste contracts as water evaporates from it and as the chemical process of hydration progresses. The effects of this volumetric change are restrained through the bond to the existing concrete and can result in cracking and debonding at the interface. In addition, tensile stresses develop in the repair material. As tensile stresses accumulate and exceed the tensile capacity of the patch material, cracking and debonding of the repair section can occur where the stress concentrations are highest or where the bond strength is weakest. It should also be noted that the Type III Portland Cement that WisDOT used in Mn/DOT's 3U18 mix has a higher shrinkage potential than Type I Portland Cement.

<u>Dowel Bar Issues</u>

The Nuovinox stainless steel clad dowel bars were not uniform in diameter size. This created a big problem when fitting them with end caps, as some were too tight and some were too loose. The tight fitting end caps often cracked under the pressure of being forced on and had to be replaced. The loose fitting end caps frequently fell off during the transportation of the bars and were easily blown off by the leaf blower when the slots were blown clean. Some loose fitting end caps even came off as the slots were being backfilled with patch material. These caps rose to the top of the patch material where they were removed and discarded. Trying to fit them back on would only have caused more of a problem, as it would have trapped patch material within the cap. It should also be noted that the Nuovinox dowel bars used were in WisDOT's possession for nearly one year, and had rust present on the bars a few weeks prior to the DBR project. The crate containing the dowel bars was stored outdoors at the WisDOT Central Office, which is believed to be the cause of the rust. Nonetheless, the rust observed was merely surface rust, and there was no penetration or pitting detected. The corrosion was removed from the Nuovinox dowel bars by wire brush just days prior to the placement of the bars.

PATCH MATERIAL TEST RESULTS

Laboratory analyses performed by the WisDOT Materials Lab included evaluating the compressive strength at 7 and 28 days, hardened air void content, permeability, and freeze/thaw durability of each patch material type, as shown in Table 1 on page 43.

Compressive Strength

For this study, it was required by WisDOT that the patch materials reach a compressive strength of 2,000 psi at an age of two hours and 4,000 psi at an age of seven days. The high early strength of the patch material is necessary so that traffic can be placed back on the retrofitted lanes soon after the process is completed. All four brands of patch material mixes used in this study were tested by the WisDOT Materials Lab (in accordance with ASTM C39) prior to construction and met these qualifications. However, testing of the cylinders made on site found that the ThoRoc 10-60 Rapid Mortar at 60% extension failed to reach 4,000 psi at seven days. This was the mix that had the calibration problems so the inconsistencies of the patch material may have played a factor in its low strength. All of the other samples made on site passed the compressive strength requirements.

Air Void Content

Entrained air contents are also reported in Table 1 on page 43. Past field experience has shown poor correlation between air void parameters and the durability of the proprietary mixes. Thus, no conclusions regarding the strength or durability of the samples could be made from the data at this point.

Permeability

Permeability tests (in accordance with ASTM C1202) were also conducted on samples taken from the DBR cores. Permeability testing measures the electrical conductivity of the patch material samples. It has been found that the total charge passed through the patch material is related to the resistance of the specimen to chloride ion penetration[2]. The permeability results were favorable for all samples tested, except the Mn/DOT Specification 3U18 mix which had a large total charge passed through the sample, indicating that it has high permeability and low resistance to chloride ion penetration. Very low to moderate chloride ion penetrability was found for the other patch materials. Overall, the Tamms Speed Crete 2028 at 80% extension mixed by paddle mixer showed the best results, with the lowest permeability.

Freeze/Thaw Durability

Samples taken from the DBR cores were also tested for freeze/thaw durability (in accordance with ASTM C666 modified – using 5% sodium chloride solution). All American Highway Technology and ThoRoc 10-60 cores exceeded 10% loss in mass after 300 cycles. None of the Tamms Speed Crete samples at 80% extension or the Mn/DOT Specification 3U18 samples showed a loss in mass after 300 cycles. The Tamms sample at 100% extension only showed a 3% loss in mass after 300 cycles. A standard WisDOT concrete mix typically loses 2% of mass after 300 cycles.

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[2] "Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration." *Annual Book of ASTM Standards*. 1996 ed.

Test Results Summary

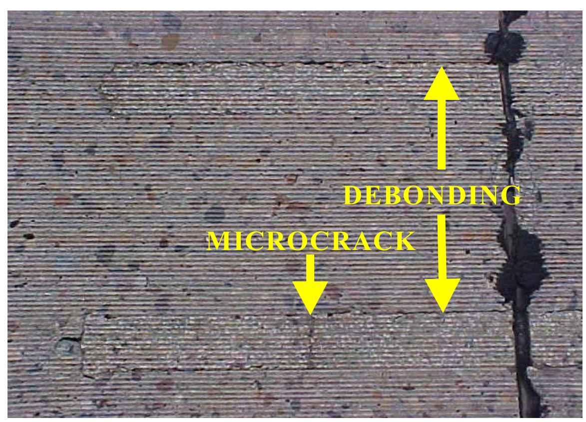
Based on the laboratory test results alone, the WisDOT Materials Lab concluded that, providing that its in situ performance is favorable, the Tamms Speed Crete 2028 (preferably at 80% extension and mixed by paddle mixer) is most suitable for use on dowel bar retrofit projects.

FIELD PERFORMANCE REVIEW

A field review was conducted May 29, 2002, approximately one year after construction. The patch material, pavement, and joints were all examined. The dowel bar patch material was visually inspected for distresses such as debonding, microcracks, and deterioration. The sealed and unsealed joints were also evaluated to determine if the joint treatment had any effect on patch material deterioration or on the performance of DBR in general.

Patch Material Performance

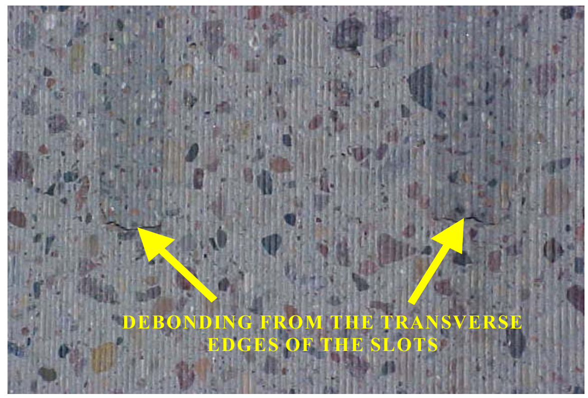
Debonding and microcracks were observed in both the Mn/DOT Specification 3U18 and Tamms Speed Crete 2028 test sections. As previously mentioned, it is believed these distresses are caused by drying, plastic, and chemical shrinkage. The Mn/DOT Specification 3U18 test sections, located in the southern half of the northbound driving lane, exhibited debonding of the patch material from the dowel bar slot sidewalls and, in some locations, from the transverse ends of the slots (Photograph 32).



Photograph 32. The Mn/DOT Specification 3U18 test sections exhibited both debonding and microcracks in some areas.

The debonding was present to varying degrees in the majority of slots over about 75% of the length (approximately the southern quarter and the northern half) of the Mn/DOT Specification 3U18 test sections. Microcracks were also present in many of the slots throughout those same areas. A couple of the slots had multiple cracks, creating loose chunks of patch material. Approximately 25% of the Mn/DOT Specification 3U18 test sections is performing well, with little to no debonding or microcracking present.

Debonding and microcracks were also observed in the Tamms Speed Crete 2028 test sections, located in the southbound driving lane of STH 13. The debonding in this section also occurred at the sidewalls or at the transverse ends of the slots (Photograph 33). Some areas had a fair amount of debonding and microcracking, while other areas showed minimal distresses and appeared to be performing quite well. The microcracks that existed were consistently very fine and tight, as opposed to the Mn/DOT sections where it appeared that some of the cracks were more open. Cores taken from both the Tamms and the Mn/DOT 3U18 sections showed that the microcracks don't extend far below the surface; thus, the surface microcracking is most likely due to evaporation of water from the surface. The severity and frequency of the debonding varied throughout the length of the Tamms test sections, but was typically less severe than the debonding that occurred in the Mn/DOT test sections. The area of the Tamms sections with the greatest amount of debonding and microcracking present was near the south end. It should be noted that construction of the Tamms Speed Crete 2028 test sections began at the north end, where calibration problems were prevalent. Calibration problems were resolved as construction continued to the south and the method for mixing the patch material was switched to a paddle mixer. Thus, even with a consistent mix, the Tamms Speed Crete 2028 is showing signs of distress in the form of microcracking and debonding.



Photograph 33. Debonding of the patch material from the transverse edge of the dowel bar slots was observed in the Tamms Speed Crete 2028 test sections.

It should also be mentioned that the Tamms Spede Crete 2028 is marketed as a nonshrink mortar that normally requires no moist curing or curing membranes. Nonetheless, the water-based, wax type, curing compound *Sealtight 1600-White* was sprayed over the Tamms slots on STH 13, as with the remainder of the project. However, it was observed that at times during the construction of the Tamms sections, the application of the curing compound was delayed, which could have caused a reduction in its water retention capability. WisDOT's specifications state that a curing compound should be applied to a concrete surface "as soon after finishing operations as the free water has disappeared".

All of the other patch materials were in excellent condition with virtually no signs of debonding or microcracking. None of the patch materials showed any signs of mortar deterioration or scaling.

<u>Pavement Performance</u>

A section of pavement starting from the southern end of Test Section A and continuing north for about 550 feet had 12 joints with severe cracks that extended from the corners of the outside dowel bar slots to the outside edge of the pavement (Photograph 34). Approximately half of these joints only had the cracking on the upstream side of the joints (Photograph 35). These cracks are located in the Mn/DOT Specification 3U18 test section, where significant debonding of the material to the sidewalls was observed in the majority of slots.

Photograph 34. One year after construction, cracking was found extending from the corners of the outside dowel bar slot to the outside edge of pavement.

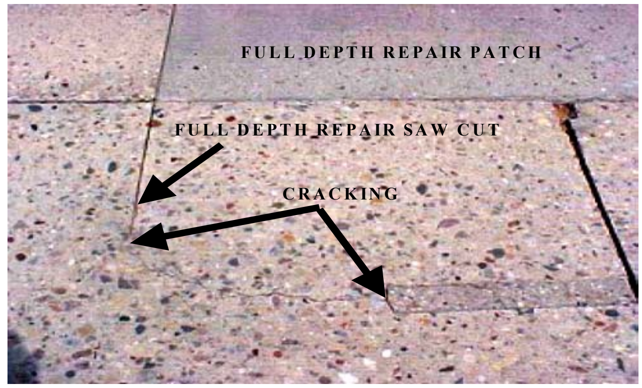
Photograph 35. Some of the slots with cracking in the outside edge of the pavement only had cracks on the upstream ends of the slots.

Another section of pavement in the northern half of Test Section J also had about a dozen joints with similar edge cracking. The cracks in this section are not as severe as those in the Mn/DOT section, as many of them are still in the early stages of cracking. In fact, some of the cracks, which start at the edge of the slots, haven't reached the edge of the pavement yet. These cracks are located in the Tamms Speed Crete 2028 test section, where a fair amount of debonding of the material to the sidewalls was observed.

A closer observation of these cracks revealed that some of the cracks begin from the sidewall of the slot, while others begin from the corner of the slot. In most cases, the cracks seemed to start at the edge of noticeable debonding. At a couple of joints in the Tamms section, the cracks started from the sidewall of the second slot over from the outside edge, instead of the outside slot. At these locations, it was noticed that the material in the outside slots appear to be well bonded to the sidewalls, but some debonding was observed in the second slot, where the cracks started. One theory is that, since the cracks seem to propagate from a debonded sidewall or a debonded transverse end, the lack of bonding caused the pavement between the edge of the slot and the edge of the slab to become somewhat isolated from the remainder of the slab. When subjected to heavy loads, the isolated portion of the slab suffered fatigue failure due to accumulated stresses within the slab. Fatigue failure caused the isolated portion of the slab to crack, from the edge of the slot to the edge of the pavement. Another theory was that the jackhammering process created microcracks in the existing pavement, which eventually led to full depth cracks after repeated loadings. Cores taken, still in the early stages of corner cracking, revealed that the cracks initiated from the top of the pavement and propagated downward after repeated loadings. This revelation discredited the theory that the cracks were a result of the jackhammering process, since cracks of this nature would propagate from the bottom or side of the slots.

It was also noticed that the distance from the outside dowel bar slot to the pavement edge varied along the project, and was either one foot or two feet, depending upon the width of the driving lane (11 or 12 feet). In the areas where cracking occurred, the distance from the outer slot to edge of pavement was only one foot. WisDOT's DBR Standard Detail Drawing specifies spacings from the centerline; thus, spacing from the outside slot to the edge of pavement can vary based on the pavement width.

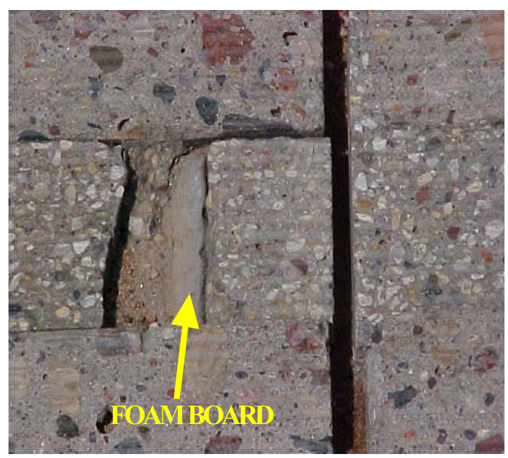
A similar type of cracking also occurred in several areas near pavement sections that had received full depth repair. The cracks extended from the corners of the dowel bar slots to the ends of the full depth repair saw cuts (Photograph 36).



Photograph 36. One year after construction, cracking was found extending from the corners of the outside dowel bar slot to the ends of the saw cuts from full depth repair sections.

Joint Performance

Thus far, the sealing or "unsealing" of joints has not affected the overall performance of the DBR or the patch materials. The joints in all of the test and control sections were performing well at the time of the field review. However, examples of poor workmanship of "finishing the joint" were observed in a few areas. Some locations did not have the foam board centered within the joint (Photograph 37).



Photograph 37. Cracking was present around the foam board at some joints where no care was taken to keep the foam board centered at the joint.

It is believed that in these cases the foam board tilted or shifted as the patch material was added to the slot. The surface of the foam board was then covered with mortar and not visible until the pavement/mortar material was diamond ground. In extreme cases, as shown in Photograph 37, the foam board is about 2 inches off from the joint and the patch material is loose on both sides of the foam board. It is just a matter of time before the loose material becomes dislodged. Other locations had extremely messy saw cuts from restoring the joints (Photograph 38). In some locations, it was observed that the joint sealing was sloppy with sealant spilled on the adjacent pavement (Photograph 39).

Photograph 38. This photo shows the sloppy work that occurred at some of the joints when they were restored with a saw cut.

Photograph 39. Sealant was spilled onto the pavement when this joint was sealed.

Also, old sealant that was no longer intact was found in the joints of Control Section 1, a section where the old sealant was supposed to be removed and left unsealed.

Dowel Bar Performance

There was no observable difference in performance, due to dowel bar type, between the test section with the Nuovinox stainless steel clad dowels and the sections with epoxy coated dowel bars. Cores were taken of the dowel bars after one year in service. Both the Nuovinox stainless steel clad dowels and the epoxy coated dowel bars are performing well to date, with no rust visible.

Field Review Summary

The Mn/DOT Specification 3U18 and Tamms Speed Crete 2028 patch materials are showing some signs of in situ distress (i.e. debonding and cracking). The other two patch materials, American Highway Technology and Thoroc 10-60, show no distresses after one year in service. Annual field reviews will be conducted over the next four years to establish performance variations and help determine the “best” patch material to be recommended for future WisDOT DBR projects.

It should be mentioned that the initiation of the I-39 RED Report, and consequently the WisDOT moratorium on DBR, was largely due to deterioration of the patch material in a large number of DBR slots throughout that project. The patch material used on the I-39 DBR project was ThoRoc 10-60C cement concentrate at 100% extension, and was mixed by a mobile mixer. The ThoRoc 10-60 used on the STH 13 project was only at a 60% extension, included both the “single component” mix and the cement concentrate, and was mixed by mobile mixer. Thus far, all three ThoRoc test sections on STH 13 are performing well. The long-term performance of all the patch materials has yet to be determined.

COST

Patch material mixes with higher extension ratios have higher yields since they have a larger proportion of coarse aggregate. In order to achieve equal yields of patch material, a mix with a higher extension does not require as much sand, cement, and water as a mix with a lower extension. So, for comparison purposes, the cost to fill 25 joints (with six slots per joint) was evaluated for each patch material mix. It was estimated that each joint would require approximately 1.77 ft^3 of patch material. This volume of patch material accounts for the volume of the slots, minus the volume occupied by the 18-inch long dowel bars, plus an additional 5% of patch material for excess. At 1.77 ft^3 of patch material per joint, approximately 44.36 ft^3 of patch material is required to fill 25 joints. By multiplying the required patch material yield for 25 joints (44.36 ft^3) by the unit weight of concrete (approximately 150.0 lbs/ft^3), the total *theoretical* weight of all patch material components required (cement, sand, coarse aggregate, and water) was found to be 6431.78 lbs.

Based on a total patch material weight of 6431.78 lbs., mix proportion ratios, and the maximum amount of water suggested by the patch material mix manufacturers, the individual weights of the patch material components were approximated. The unit prices charged on this specific dowel bar retrofit project were then used to calculate individual material and total costs as shown in Table 2 on page 44. Since project location (e.g. proximity to a quarry, shipping distance of mortar material, the abundance of material in that region, etc.) and project size (e.g. bulk order discounts) can greatly influence component prices, it is important to remember that the unit prices will vary between projects.

Of all the patch material mixes tested, the Tamms Speed Crete 2028 was the most expensive mix. This mix also increased in price when it was purchased in smaller units (50 lb bags instead of 2000 lb bags), which occurred when the patch material was mixed in small batches using a paddle mixer. In addition, it should be reiterated that the Tamms mortar mix required the use of a paddle mixer for it to be satisfactorily mixed, therefore, had a much slower productivity rate. The second most expensive mix was the ThoRoc 10-60 Rapid Mortar. However, the cost of the ThoRoc product dropped when the concentrated mix, ThoRoc 10-60C Rapid Cement, was used to resolve the mixing problems. This ThoRoc 10-60C Rapid Cement was third most expensive followed by the American Highway Technology Highway DB Retrofit Grout and the Mn/DOT Specification 3U18 Concrete Mix respectively. The Mn/DOT mix was substantially less expensive than all of the other mixes.

As one of the first states to test the Nuovinox dowel bars, they were provided to WisDOT free of charge for evaluation purposes. Thus, the actual cost of the Nuovinox dowel bars used in this project is not a realistic representation of their current standard cost, therefore, is not used in this report. In addition, the shorter size of the Nuovinox dowel bars, 15 in. as opposed to 18 in. for the epoxy coated dowel bars, do not provide for a fair comparison. Instead, for comparison purposes, the current cost of an 18 in. long, 1¼-inch diameter, Nuovinox stainless steel clad dowel bar is used. As of July 2002, the standard cost of an 18 in. long, 1¼-inch diameter, Nuovinox dowel bar, as quoted by Stelax Industries, Ltd., was approximately \$5.55, delivered. For informational purposes only, the current standard cost of a 15 in. long, 1¼-inch diameter, Nuovinox dowel bar is $3.65, delivered; and, the cost of an 18 in. long, 1½-inch diameter, Nuovinox dowel bar is $7.66, delivered. It should be noted that these prices may not reflect actual future costs of similar dowel bars based on future market development. A bond breaker such as WD-40 must be applied to these bars as well, at an additional cost of around $0.01 to coat the surface of one dowel bar. Standard 18 in. long, 1¼-inch diameter, epoxy coated steel dowel bars cost, on average, $2.18 per bar, including delivery. Thus, the Nuovinox stainless steel clad dowel bars cost approximately two and a half times as much as epoxy coated dowel bars. Nuovinox dowel bars, however, are approximately half the cost of type 316L alloy solid stainless steel dowels. It is still too early in the study to determine if one type of dowel bar will outperform the other, or which type of bar is most cost-effective.

CONCLUSIONS & RECOMMENDATIONS

With respect to dowel bar installation, the deteriorated joints at the base of the slots presented a lot of problems. Using sand to fill the deteriorated areas is not an effective remedy. The sand is easily blown out of the slots and the sand that remains absorbs and holds water, which could lead to more deterioration at the joint. On this specific project, the majority of the slots with bottom up deterioration were deteriorated severely enough so that inserting a longer piece of foam board to maintain the joint all of the way through to the bottom of the slab would have been a feasible remedy. It is recommended that if deteriorated joints at the base of the slots are encountered in the future, and the voids due to deterioration are wide enough, longer foam board be used to maintain the joint. Alternative solutions for slots with bottom up deterioration, such as filling the voids with an economical elastic material, should also be investigated. Full depth repairs should be considered in areas where bottom-up deterioration warrants.

Unexpected areas of thin pavement also created problems, as there was no reliable method to keep the dowel bars at mid-pavement depth. In the future, in areas where thin pavement is possible, ground penetrating radar, cores, or other suitable methods should be used to verify the pavement thickness prior to the project letting. The slots should be cut to a shallower depth in areas where thin pavement is identified.

There were also problems with fitting the Nuovinox stainless steel clad dowel bars with end caps, due to inconsistent diameter sizes of the dowels. Some end caps were too tight and cracked when forced on the dowels; and, others were too loose and tended to fall off during transportation or when the slots were backfilled with patch material. It is recommended that these bars not be used on other dowel bar retrofit projects until the manufacturer can assure that all of the dowel bars will be uniform in diameter.

A mobile mixer is not capable of consistently mixing “single component” mortar mixes, which have the sand and cement pre-mixed by the manufacturer, because of segregation in the hopper. Unless a volumetric mixer that can mix “single component” mortar mixes satisfactorily is found, a paddle mixer should be required for “single component” mixes such as the Tamms Speed Crete 2028 Rapid Setting Mortar. It is important to note that the use of a paddle mixer will significantly decrease the level of productivity as compared to productivity levels with a mobile mixer.

Cracking of the pavement from the dowel bar slots, just one year after construction, is also an issue of concern. These cracks extended to the edge of the pavement in some cases and to full depth repair saw cuts in other cases. It is recommended that the cause of this distress be further investigated, as the cracking is fairly severe in some locations. It is also recommended that WisDOT specifications be changed to require a minimum distance of 18 inches from the edge of pavement to the outer dowel bar slot.

It is believed that the causes of the debonding and the microcracking of the Mn/DOT Specification 3U18 mix and the Tamms Speed Crete 2028 Rapid Setting Mortar are drying, plastic, and chemical shrinkage.

It is recommended that WisDOT investigate possible methods of alleviating the shrinkage and resultant debonding and microcracking, such as:

- low-shrink cements or expansive cements to substitute for the Type I in the Mn/DOT 3U18 mix,
- low-shrink or expansive admixtures to supplement the Mn/DOT 3U18 mix with Type III cement,
- water-saturated lightweight coarse or fine aggregate in lieu of a portion of the aggregate or sand to provide internal curing, and
- alternative curing compounds/methods.

Poor consolidation of the patch material around the dowel bars was also a problem with the Mn/DOT Specification 3U18 mix. Two of the four Mn/DOT Specification 3U18 cores taken showed that the patch material did not consolidate well and failed to fully encase the dowel bar. This is most likely due to the low slump requirements of this mix. The stiffness of the material makes it difficult to vibrate in place. No single patch material appeared to outperform the others in terms of workability, but the Mn/DOT Specification 3U18 Concrete Mix had the poorest workability.

The Tamms Speed Crete 2028 Rapid Setting Mortar performed the best in the laboratory testing conducted by the WisDOT Materials Lab. However, the one-year field performance review indicated that the Tamms mortar was one of only two patch material types showing slight signs of distress. Both the Tamms Speed Crete 2028 and the Mn/DOT Specification 3U18 patch materials showed debonding and microcracks. The other patch materials are performing well to date.

Good workmanship is a key factor in DBR projects. The placement of the foam board, particularly, can create problems if not aligned correctly with the joint. It is recommended that DBR construction and inspection personnel receive proper training in current construction practices prior to undertaking a DBR project.

IMPLEMENTATION PLAN

- WisDOT's District 4 constructed another DBR project in the summer of 2002 in Clintonville, Wisconsin. The project consisted of about 3 lane-miles of DBR. The Tamms Speed Crete 2028 Rapid Setting Mortar was used on 2.25 lane-miles, while Set 45 patch material was used on 0.75 lane-miles. In addition, a resin-based curing compound and a water-based curing compound were both used on this project. The performances of these sections will be monitored by WisDOT's District 4 and Technology Advancement Unit personnel.

- WisDOT will investigate methods to control early age shrinkage such as low-shrink cements or expansive cements, low-shrink or expansive admixtures, water-saturated lightweight coarse or fine aggregate in lieu of a portion of the aggregate or sand to provide internal curing, and alternative curing compounds.

- WisDOT's Technology Advancement Unit and Physical and Chemical Testing Unit will jointly develop a work plan to conduct in-house laboratory tests on several PCC patch materials modified with the aforementioned methods. Samples will be prepared and tested in WisDOT's Materials Laboratory.

- A meeting will be scheduled in the near future, between WisDOT, Wisconsin Concrete Pavement Association (WCPA), and Federal Highway Administration (FHWA) personnel, to discuss possible changes to WisDOT's DBR specifications. Recommended changes will include:

    - Provide guidance on how to best deal with voids, and how to maintain the joint in the slots with voids, caused by deterioration of the concrete pavement.

- Require a minimum distance of 18 inches from the edge of pavement to the outer dowel bar slot. The minimum distance from the inner dowel bar slot to the centerline will be changed from 24 inches to 18 inches.

- Require a paddle mixer to be used for "single component" mortar mixes unless the contractor can prove a consistent, satisfactory mix can be produced by some other means.

- Specify 100% pure silicone caulk to be used to seal the cracks; and, specify that water-based siliconized acrylic caulk will not be permitted.

- Suggest the use of thicker foam board or multiple foam board spacers in slots with wider joints.

- Require DBR construction and inspection personnel to receive proper training in current construction practices prior to undertaking a DBR project. Coordinate with WCPA to initiate the training.

- STH 13 will continue to be monitored through 2006, at which time the project will have five years of in-service performance. A final report evaluating patch materials, joints, dowel bars, and overall pavement performance will be prepared at that time.

Appendix A

(Figures and Tables)

Figure 1. Project Location Map

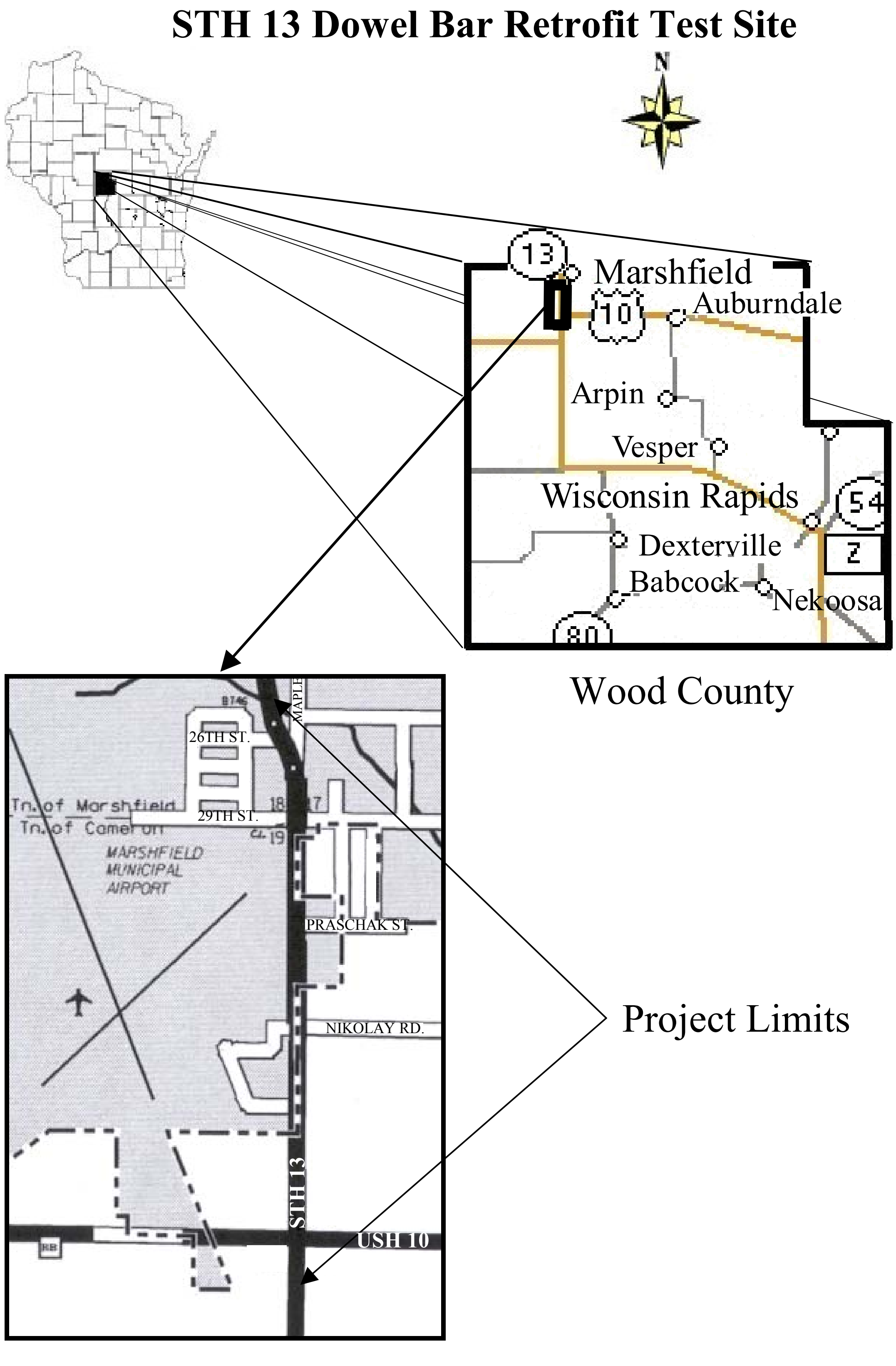
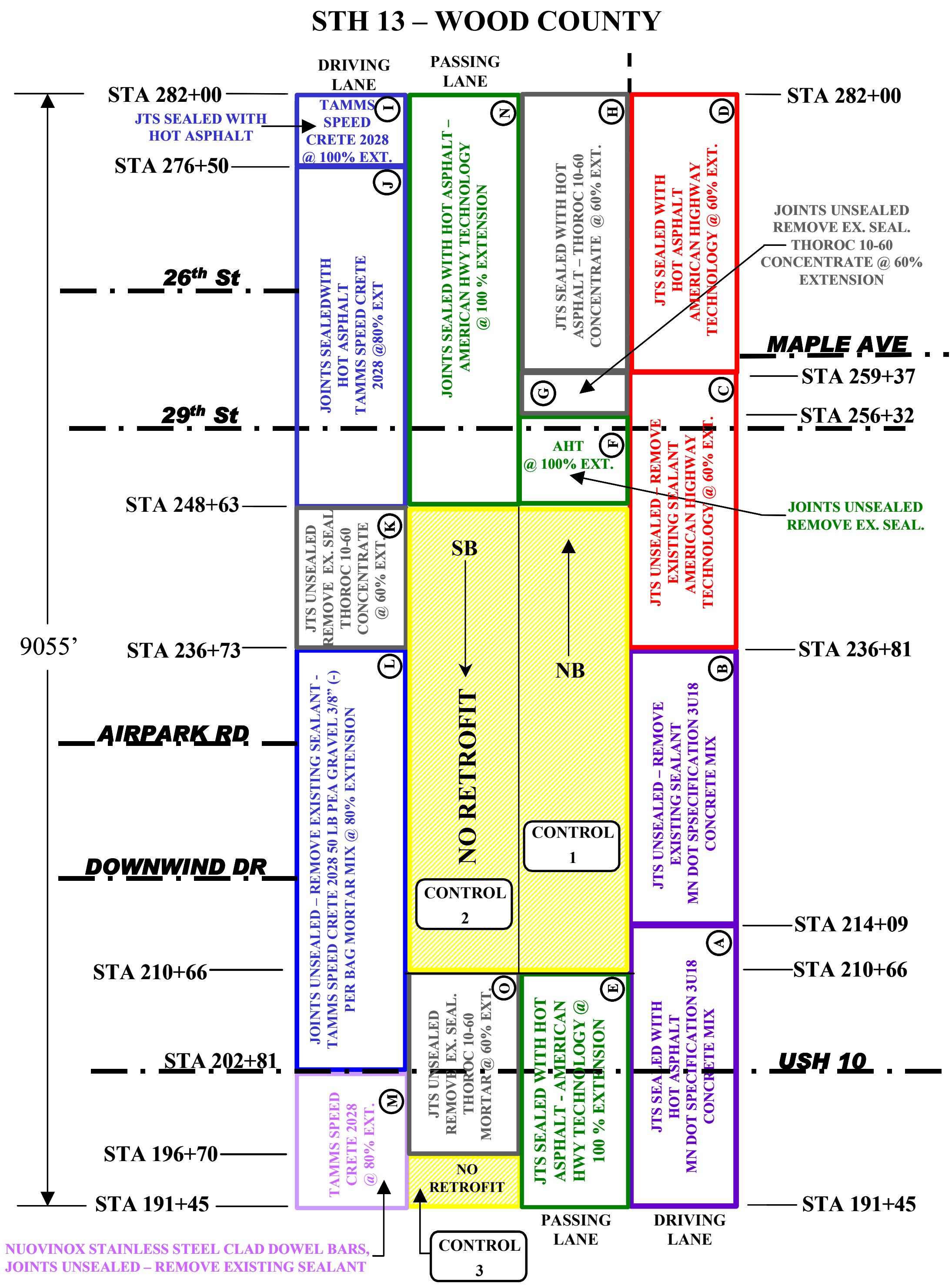


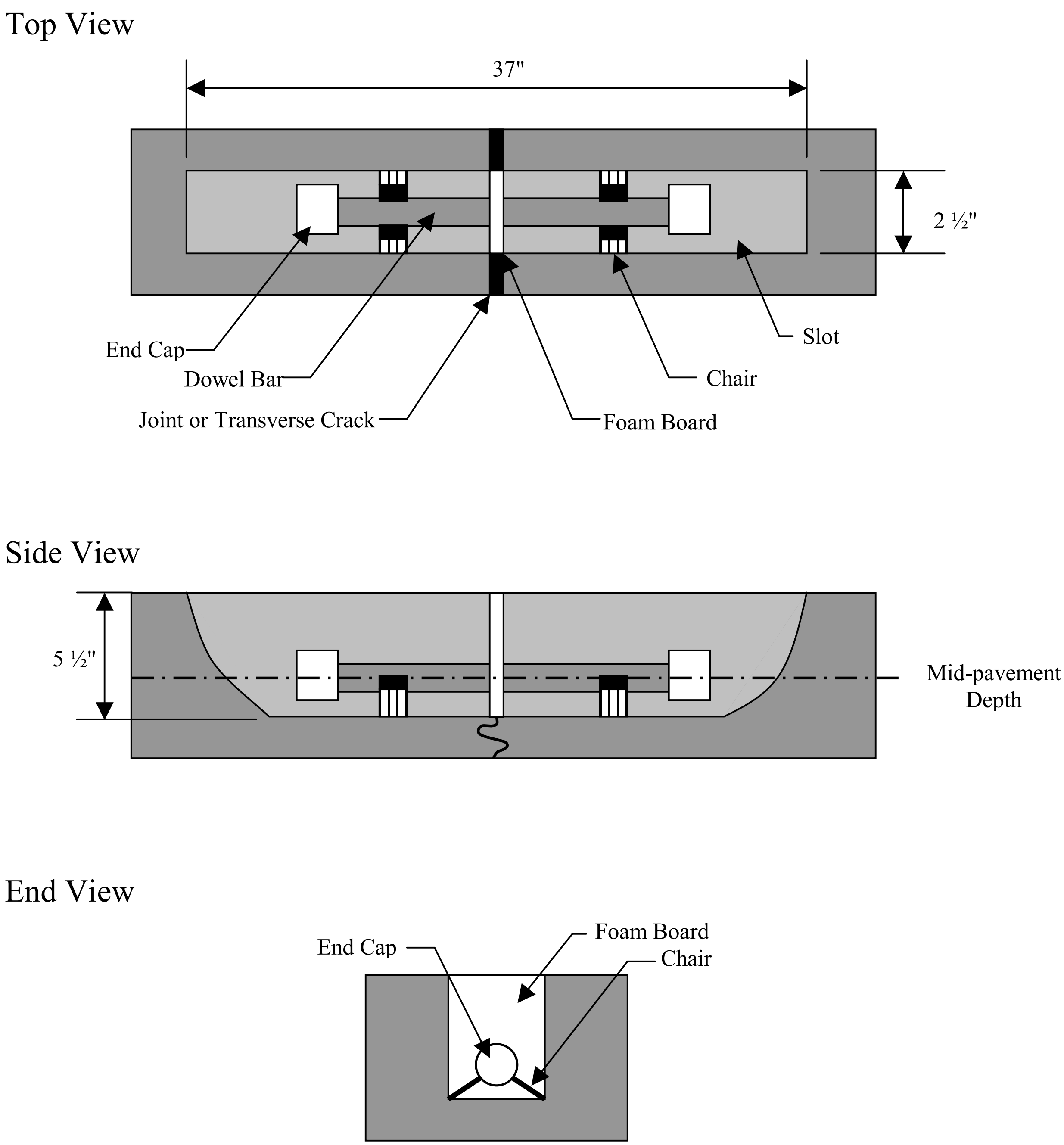
Figure 2.   Test Section Layout



Note: The circled letters are for reference purposes only; they do not indicate order of construction.

*** Not to Scale ***

Figure 3. Dowel Bar Placement Diagram



*** Not to Scale ***

Table 1. Patch Material Test Results

Patch Material	Extension (%)	ASTM C39 Compressive Strength, psi 7 day	28 day (avg.[1])	ASTM C457 Entrained Air[2] (%)	ASTM C1202 Permeability Test[4] (Coulombs) 7d	28d	90d	ASTM C666 mod.[6] Freeze / Thaw Durability Test[2]
American Highway Technology Highway DB Retrofit Mortar	60	8280	8170	2.8, 3.6	NA[3]			21% and 35% loss @ 300 cycles
American Highway Technology Highway DB Retrofit Mortar	100	5350	6195	3.8	1755	1173	566	10% loss @ 300 cycles
Tamms Speed Crete 2028 Rapid Setting Mortar	100	7580	8950	6.0	1348	1112	1002	3% loss @ 300 cycles
Tamms Speed Crete 2028 Rapid Setting Mortar	80	6160	7770	5.0	1565	1536	1298	0% loss @ 300 cycles
Tamms Speed Crete 2028 *Mixed by Paddle Mixer*	80	5430	6555	7.9, 10.7	1144	882	458	0% and 0% loss @ 300 cycles
Thoroc 10-60 Rapid Mortar *Cement Concentrate*	60	NA[3]	NA[3]	5.3	NA[3]			25% loss @ 300 cycles
Thoroc 10-60 Rapid Mortar	60	3530	5685	7.3	2040	1408	628	11% loss @ 300 cycles
Mn/DOT Specification 3U18 Concrete Mix	-	5120	5850	3.7, 5.2, 6.6, 7.2	8365	5853	4358	-1%, -1%, 0%, and 0% loss @ 300 cycles[5]

Note:
1: The 28 day compressive strength is the average strength taken from two separate cylinder breaks.
2: Multiple values for "Entrained Air" and "Freeze/Thaw Durability Test" indicate that multiple samples (cores) of that mix were analyzed.
3: Not enough cylinders of the American Highway Technology Mortar at 60% extension were taken to conduct permeability tests; and, no cylinders of the Thoroc 10-60 Mortar from cement concentrate were taken to conduct compressive strength or permeability tests.
4: 7d, 28d, and 90d refer to the chloride ion penetration of the mortar samples (cylinders) after 7 days, 28 days, and 90 days respectively.
5: Negative percentages for "Freeze/Thaw Durability Test" indicate hydration and chloride ion gains.
6: The "Freeze/Thaw Durability Test" conducted is a modified version of ASTM C666 using material from the field samples (cores) and 5% sodium chloride solution.

Table 2. Cost Analysis for 25 Joints (44.36 C.F.) of Patch Material (using this project's unit costs)*

Patch Material	Extension (%)	Mixing Ratio mortar : aggregate or cement : sand : aggregate	Cost Per 25 Joints (Using Theoretical Yields)				
			Water	Cement	Sand	Aggregate	Total
Tamms Speed Crete 2028 Rapid Setting Mortar	80	1: 0.8	351.63 LBS. $0.00	3377.86 LBS. $942.42		2702.29 LBS. $10.81	6431.78 LBS. **$953.23**
Tamms Speed Crete 2028 Rapid Setting Mortar	100	1 : 1	318.22 LBS. $0.00	3056.78 LBS. $852.84		3056.78 LBS. $12.23	6431.78 LBS. **$865.07**
ThoRoc 10-60 Rapid Mortar	60	1 : 0.6	501.83 LBS. $0.00	3706.22 LBS. $630.06		2223.73 LBS. $8.89	6431.78 LBS. **$638.95**
ThoRoc 10-60C Rapid Cement (Cement Concentrate)	60	1 : 1.5 : 1.5	500.32 LBS. $0.00	1482.86 LBS. $400.37	2224.30 LBS. $7.79	2224.30 LBS. $8.90	6431.78 LBS. **$417.05**
American Highway Technology Highway DB Retrofit Grout	60	1 : 1.5 : 1.5	463.58 LBS. $0.00	1492.05 LBS. $343.17	2238.07 LBS. $7.83	2238.08 LBS. $8.95	6431.78 LBS. **$359.96**
American Highway Technology Highway DB Retrofit Grout	100	1 : 1.5 : 2.5	376.28 LBS. $0.00	1211.10 LBS. $278.55	1816.65 LBS. $6.36	3027.75 LBS. $12.11	6431.78 LBS. **$297.02**
Mn/DOT Specification 3U18 Concrete Mix	-	1 : 1.57 : 1	582.77 LBS. $0.00	1638.38 LBS. $67.99	2572.25 LBS. $9.00	1638.38 LBS. $6.55	6431.78 LBS. **$83.55**

Yields were calculated using the maximum water allowances:
Tamms allows a maximum of 0.0125 gallons (0.1041 pounds) of water per pound of *mortar* (sand + cement).
ThoRoc allows a maximum of 0.01625 gallons (0.1354 pounds) of water per pound of *mortar* (sand + cement) and 0.0405 (0.3374 pounds) gallons of water per pound of cement.
American Highway Technology allows a maximum of 0.0373 gallons (0.3107 pounds) of water per pound of *cement*.
Mn/DOT Specification 3U18 requires approximately 0.0427 gallons (0.3557 pounds) of water per pound of *cement* to achieve a slump of 1.5 inches (as per ACI estimations).

* Please note that 44.36 C.F. is the **theoretical** volume of patch material necessary to fill 25 joints. The actual volume of material used was much greater due to mix inconsistencies and the resulting waste of material.